C. E. Baum
22 October 1988

Microwave Memos

Memo 1

A Rational Approach to the Development of an HPM Weapon

I. Introduction.

In considering the possible development of a high-power-microwave (HPM) weapon, one needs to define the problem. What is it that one is trying to do? One can design a high-power jammer which is tailored to some particular subsystem, such as the operating frequency of a radar. This is not, however, what we are considering here. We are considering the more general problem of damaging or upsetting electronic equipment via faults in the system design such as through windows, doors, antennas (out of operating band), and conducting penetrations (power and communications lines etc.). Some refer to this as "back door coupling". This is usually the principal EMP coupling problem.

The general industrial world (with a few exceptions) does not understand basic electromagnetic concepts, including elementary consistent shielding and grounding. This fact can be exploited in designing an HPM weapon. (This is perhaps a new application of the military maxim: "Hit 'em where they ain't!")

If, however, one wishes to design an HPM weapon, it behooves one to understand what the real system vulnerabilities of this type are. What frequencies, pulse widths, and amplitudes should one use? For what potential target systems (theirs and ours) should one find the answer to these questions?

Having decided (at least tentatively) what environment an HPM weapon should produce, then one can investigate the feasibility of building such a thing. This involves questions of range, cost, weight, size, peak power, pulse width, etc.

II. The Target - Interaction Problem.

Designing an HPM weapon is strongly influenced by the electromagnetic properties of the target. The great complexity of real systems makes this basically an experimental problem. One can make models of the interaction process by beginning with the electromagnetic topology of the system to break it into smaller parts for analysis according to the layers of the system [10]. While this can help guide one's understanding of the system response, it is in most cases foolish to rely totally on such analysis. EMP test experience has shown that systems are just too electromagnetically complex. A realistic case has just an enormous number of variables. Usually the system designers have not been smart enough to use the EM topology to control the number of penetrations and then control every penetration. Often one finds things like wires in real systems that the drawings do not show; they may have been added later by other than the system designers for some "convenience". Needless to say such can be the Achilles heel of the system. Well, one person's vulnerability can be another person's opportunity.

So, how does one determine what the potential HPM vulnerabilities of some system really are? Assuming one has one of these, there are various possibilities. One can blast away with some HPM source that one has, but why should one assume that this is the right source? Are the frequencies, pulse widths, and amplitudes correctly chosen? As one should anticipate, the likelihood of choosing these parameters a priori in an optimum manner is rather small. Of course, if the test produces an actual failure, one can consider that a data point around which to design a weapon. However, why should we assume that this in any sense is optimum? Perhaps another weapon would be more effective in terms of cost, range, etc.

Another approach involves using low-level microwaves (this technology being around for about a half century). Basically one uses standard horn or reflector antennas with low-level sources. Anticipating an optimum frequency around a GHz [1] one can cover the range of about 100 MHz to 10 GHz. The basic concept is to measure the transfer functions from incident fields to response at some potential failure port [2]. This should usually exhibit a resonant behavior. Then one determines the optimum frequencies ω_s and damping constants Ω_s for an ideal source matched to the experimentally determined resonances [3]. Combined with a peak microwave field the transfer-function information gives an estimate of the transient signal at the failure port. Various characteristics of this transient signal (such as peak (or ∞-norm) or energy (related to 2-norm)) can be used to estimate potential failure (including upset) at the port. This gives an estimate of the required microwave frequency ω_s, damping constant Ω_s, and amplitude E_o (say for electric field) to give failure. Note that various directions of incidence and polarization will be necessary, with transfer functions as a function of frequency for each.

There are, of course, limitations to this approach. In going from transfer functions to transient signals associated with failure, nonlinear processes in general enter. However, engineering experience indicates that linear concepts can usually be used to scale up to amplitudes for which the nonlinear failure processes (including failure) occur, and this is all that we need. Of course, this applies only in a situation where one actually has a copy of the potential target in hand.

I do not mean to imply that this approach will find everything of significance in the vulnerability of a particular system. However, it will bring to light much of the vulnerabilities that would otherwise not be exposed except by an enormous amount of high-power testing. If desired, one could supplement the low-level testing by testing with medium-level sources that give what is high level at the system under test. The sources need only be medium level because the distance to target would be much shorter than operational weapon/target distances. Such testing would be to refine the low-level results (such as looking for significant nonlinearities). It is, however, of less importance than the low-level results (at least in a scientific/engineering sense).

As to who should accomplish the foregoing measurements and analysis, I see two skills of importance. First, it is necessary that practical electromagnetic theorists, such as built [10] be dominant in the testing and analysis. Whether these be at government labs like AFWL, or industrial research groups, or universities is only of secondary importance. First of all they must be highly competent, mostly with doctorates in the specialty of electromagnetics. See [4, 5, 6].

A second category of people concerns instrumentation. On one hand there is an enormous amount of microwave instrumentation developed over half a century by the traditional microwave community that can be called on. This can be supplemented by EMP instrumentation appropriate to the transient nature of the problem. The low-level sources and antennas can be found in catalogs and handbooks.

III. The Microwave Weapon Problem.

Now assume that the interaction problem has been properly handled. (I am not holding my breath.) From this we have some definition of peak field, frequency, and pulse width (perhaps several sets of these). With a choice of range R_o one can go back to the requisite parameters for the source and antenna to radiate the microwave pulse using the simple formulas in [1].

Concerning the antenna, there is an enormous amount of technology to which a lot of people in the HPM world seem to be oblivious. In the GHz range and for high power, the general category of antenna of concern is a reflector antenna [12]. There are many experts on such matters as one can see by reading the literature. Some of these should be brought on board.

As one goes to the feeds (and perhaps subreflectors and lenses) of the antenna system very high electric fields will be present involving vacuum, SF_6 (or freon), interfaces, lenses, etc. Here some of the EMP-pulse-power community can contribute.

Working back through one or more high-power waveguides, we come to the HPM source. A lot of good work has been done on this as evidenced by the literature [7, 8, 9, 11]. The leading candidates involve some application of magnetron/gyrotron technology. These are driven by pulsers similar to those used in EMP simulators. We start off thinking of GW for 10s of ns and extrapolate from there. The sources can be made larger and some number can be phase locked together. I think something around .1TW is a goal to shoot for. (This is still less than the power put out by existing EMP simulators.) A later discussion may consider some of the properties of what might be called a phaser.

In designing an HPM source efficiency is extremely important. Magnetrons are known to be relatively efficient microwave sources, including in the GW range. An inefficient source can be a big problem as one goes up in total energy radiated. This can be the Buck Rogers equivalent of shooting oneself in the foot.

For designing an HPM source we need the right people. Look at the literature and you will see what universities and laboratories have made the major contributions. We need cleverness besides brute force. We need graduate students working on PhD theses to develop analytic approximate design equations for efficient high-power sources. How do you think the radar problem was solved in WWII? (See the M.I.T. Radiation Laboratory series for a clue.)

IV. Concluding Remarks.

The HPM weapon problem involves both target characterization and weapon development. Much of the technology exists to solve both problems. However, more than money we need a team of competent people: electromagnetic theorists, plasma physicists, etc. And, remember: the best is scarcely good enough. Mediocre people will get nowhere and can be best utilized in supporting the experts.

Assuming the right scientists and engineers are assembled to be the technical leadership, then the function of the administration is to get them what they need when they need it and not bother them with administrative trivia. Some of these technical people will likely come from industry and academia; it is up to the administration to see that they are smoothly integrated into the team and not burdened with non-technical matters. An appropriate model is the Manhattan Project, but on a much smaller scale.

References:

1. C. E. Baum, Maximization of Electromagnetic Response at a Distance, Sensor and Simulation Note 312, October 1988.

2. C. E. Baum, Black Box Bounds, Interaction Note 429, May 1983, and Proc. EMC Symposium, Zurich, March 1985, pp. 381-386.

3. C. E. Baum, Transfer of Norms Through Black Boxes, Interaction Note 462, October 1987.

4. C. E. Baum and D. V. Giri, The Lack of Electromagnetic Skills Among EMP Related Personnel, EMP Education Memo 1, June 1977.

5. C. E. Baum, The Failure of AFWL to Retain Qualified Electromagnetics Personnel for EMP Programs, EMP Education Memo 2, January 1983.

6. C. E. Baum and D. V. Giri, Some Critical Factors in Obtaining Valid Information from EMP Tests on Complex Systems, System Test Memo 1, June 1977.

7. H. Sze, B. Harteneck, J. Benford, and T. S. T. Young, Operating Characteristics of a Relativistic Magnetron with a Washer Cathode, IEEE Trans. Plasma Science, June 1987, pp. 327-334.

8. K. L. Felch (ed.), Special Issue on High-Power Microwave Generation, IEEE Trans. Plasma Science, Dec. 1985.

9. S. H. Gold and J. M. Baird (eds.), Second Special Issue on High-Power Microwave Generation, IEEE Trans. Plasma Science, April 1988.

10. K. S. H. Lee (ed.), EMP Interaction: Principles, Techniques, and Reference Data, Hemisphere Publishing, 1986.

11. V. L. Granatstein and I. Alexeff (eds.), High-Power Microwave Sources, Artech House, 1987.

12. Y. Rahmat-Samii, Reflector Antennas, in Y. T. Lo and S. W. Lee (eds.), Antenna Handbook, Van Nostrand Reinhold, 1988.